REINFORCING METHOD OF ROCK SLOPE USING FRP PIPE

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ABSTRACT

This paper proposes a rock slope reinforcing method, which is called FRP pipe reinforcing method, to concrete the discontinuous blocky surfaces. This method replaces rock bolt with fiberglass reinforced plastic (FRP) pipe and grouts cement mortar into the discontinuous surfaces. It was observed that the proposed method is an exclusive slope reinforcing method and easily workable and economic method.

1. INTRODUCTION

Due to rising industrial and residential development, many houses and roads are being constructed which increases the number of cut slopes. In general, cut slopes usually consist of a thin layer of topsoil with ripped and blasted rock layers, which have different degrees of weathering. Rock properties and rock mass characteristics influence the slope stability in the ripped and blasted layers of rock. Slope stability is affected by external factors such as frost heaving, precipitation, earthquakes, blasting and so forth. Internal properties of the rock slope such as discontinuity are the key factor that influences the stability as well. Most of rock slope failures are occurred through this discontinuity surface. Many methods including rock bolt, nailing, and rock anchor have been proposed and used to overcome the discontinuity in the rock mass.

This paper proposes a rock slope reinforcing method which is called FRP pipe Reinforcing Method. This method cements the discontinuous rock surfaces. Fiberglass reinforced plastic (FRP) pipe replaces rock bolt and grouts cement milk into the discontinuous surfaces.

In this paper, several laboratory and in-situ tests were conducted to verify the properties and functions of the proposed method. In the laboratory tests, tensile and flexural strength tests were conducted to find the design parameters. In the in-situ tests, pull-out test and geophysical methods such as electrical resistivity and seismic refraction tests were applied in three construction sites.

2. FAILURE PROCESS IN ROCK SLOPE

Rock mass is a large size of rock which includes geological discontinuities such as joint, fault, foliation and so forth. Mechanical characteristics of rock mass depends on the geometrical shape, size, distribution of the discontinuities. It is important to investigate the engineering characteristics of the discontinuity quantitatively to evaluate the stability of rock slope.

Figure 1 summarizes the process of cut slope failure. In pre-failure stage, there is no deformation on the site and then the stability is controlled by the shear strength of reinforcing shaft. During the failure, mixed forces of shear, bending and tensile are occurred on the shaft as the deformation increases. At this stage, pull-out force is active between the shaft and sealing mortar. In post-failure stage, progressive failure is continuous. FRP pipe is dominant by the tensile strength as the vertical and horizontal deformations increase.

Through review of this failure process, it is natural that this method requires shear, bending,

tensile and pull-out tests for FRP pipe.

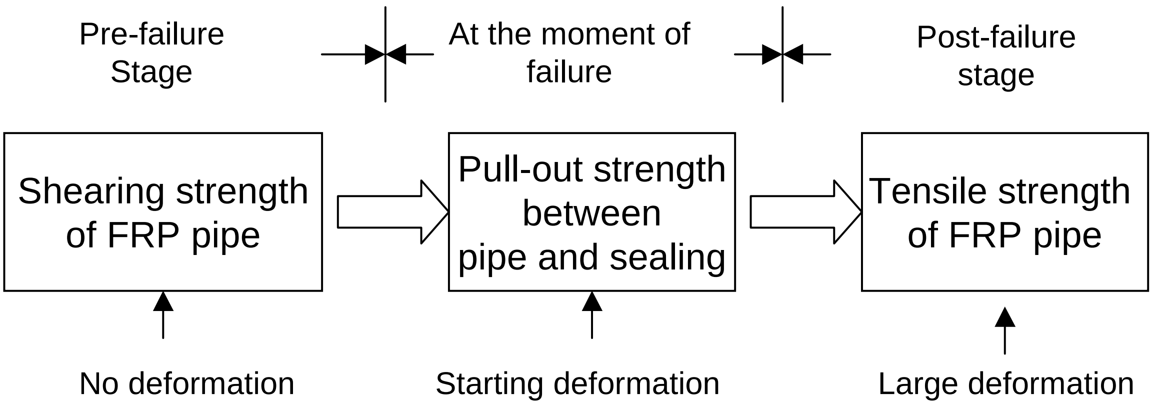

Figure 1. Failure process of rock slope

3. PRINCIPLE OF FRP PIPE REINFORCING METHOD

The FRP-pipe reinforcing method is a measure to reinforce the rock slope. This method is very similar to the rock bolt and soil nailing methods but uses a rigid FRP pipe punctured with small holes along the pipe shaft.

It is important to bond the FRP pipe with the excavated hole wall on the rock slope. In this method, two types of cement mortars called grouting mortar and Lables Wasserglass(LW) mortar are used. The grouting mortar is injected into discontinuous surfaces and the LW mortar fills the empty space between the pipe and the hole with pressure.

Figure 2 describes the basic concept of FRP-pipe reinforcing method. In this method, we first drill a hole of 105mm in diameter up to the required depth on the slope, then insert the FRP pipe into the hole. Through the pipe, cement mortar is injected at the pressure of 5kg/cm^2 and cements the blocky rock slope. Finally steel plate(300mm x 300mm) is installed on the surface end of FRP pipe. FRP pipes are installed at intervals of designed distance.

Table 1 compares the materials and process of existing methods with FRP reinforcing method. The proposed method uses FRP pipe with two types of cements mortars. The cements are injected at pressures.

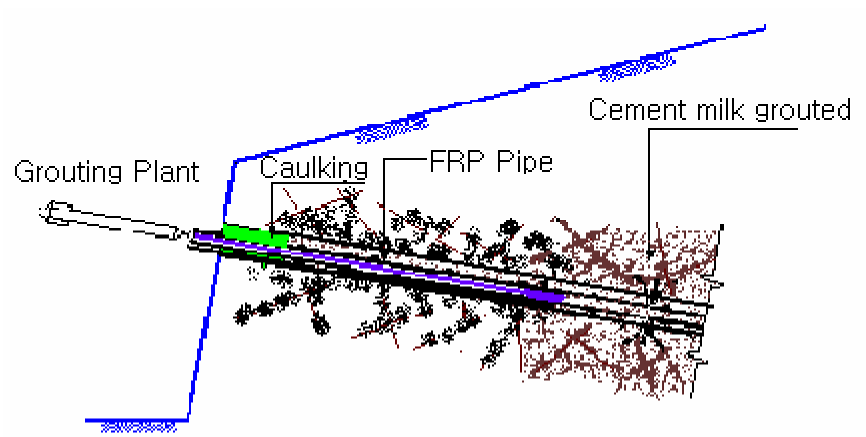

Figure 2. Basic concept of FRP pipe reinforcing method, Kim(1)

Table 1. Comparison of existing methods and FRP method

Reinforcing Method	Reinforcing Material	Sealing	Grouting
Rock bolt and Soil nailing	Steel rod	Sealing without pressure	No grouting
FRP pipe	FRP pipe plus Cement mortar	Sealing with pressure	Grouting with cement mortar

4. MANUFACTURING METHOD OF FRP PIPE

FRP pipe is manufactured with fiberglass as main component which is a composite structural member unsaturated-polyester resin. There are two main procedures in the manufacturing of FRP pipe. The first process is to wrap the shape with uni-directional fiberglass submerged in hot epoxy plastic at uniform thickness. This process will improve the tensile strength. The other one is to wind the filament on the shape which is able to resist at the high internal pressure.

Once we produce the shape of the pipe, place a prop ring at 90cm interval and then drill four small holes around the shaft at upper near prop ring. These holes will allow to flow the cement mortar into the joint surfaces on the rock mass(see Figure 3).

Figure 3. Shape of FRP pipe (Produced by Dae Won Co. Ltd, Korea)

6. LABORATORY TEST

Laboratory tests were conducted to know the engineering properties of FRP pipe as the replacing member of steel rod. With considering of failure mechanism in rock slopes, flexural strength and tensile strength tests were performed as followings.

Specimens of FRP Pipe

Two types of specimen of FRP pipe were applied in the test. As shown in Figure 4, The FRP pipe were manufactured with and without steel wires. Figure 4(a) presents the specimen without steel wire and Figure 4(b) with steel wires. Both specimens have 5 mm to 7mm in thickness, 45mm in internal diameter. Eight to sixteen Wires of 2mm of diameter are inserted into the specimen. The wires are placed to improve the tensile strength of the FRP pipe.

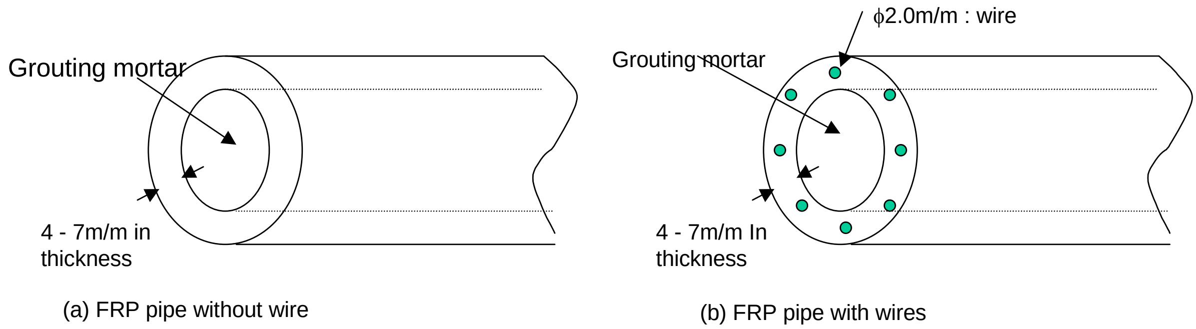

Figure 4. Specimens of FRP pipe

Flexural Test

FRP pipe which resists the slope movement, receives the shearing resistance right before occurring the slope failure. A flexural test were conducted replacing the shear strength test. In this test, steel rod and FRP pipe specimens were used as shown in Table 2. The size of steel rod is 25mm in diameter which is commonly used in rock bolt and soil nailing methods. FRP pipe is used as described in the above. The pipe was filled with cement mortar which has same conditions of field grouting.

Table 2. Dimensions of reinforcing shafts

Type	Outer diameter (mm)	Inner diameter (mm)	Thickness (mm)	Length (cm)
Steel rod	25	-	-	100
FRP pipe	42 - 47	37-40	5.0 – 7.0	100

Figure 5 shows the load-displacement behavior of steel rod and FRP pipe. In the test, the steel rod shows linearly increase up to 0.83 ton and 1.5 ton of maximum flexural strength. On the other hand, the FRP pipe without wires rapidly increases up to 3.0 ton and shows the maximum strength of 3.8 ton. As the displacement increases, the strength rapidly decreases and shows some brittle property. The specimen of FRP pipe with steel wires increases the load up to 4.0 ton and gradually increases up to 4.3 ton as a maximum load. At around 20 mm of displacement, the strength rapidly decreases and keeps the same amount of steel bar's load. The maximum load of FRP pipe becomes 2.9 times of steel bar's load. Wires embedded in FRP pipe works as composite material with fiber glass in the pipe and improves the ductile property.

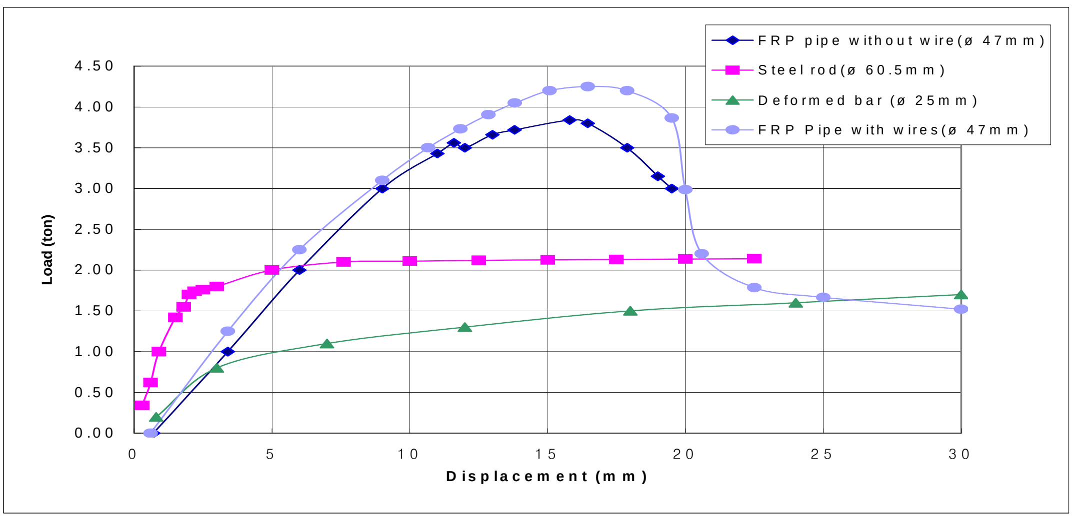

Figure 5. Results of flexural strength test

Tensile Strength Test

At the moment of slope failure, the reinforcing shaft receives tensile load due to both horizontal and vertical displacements. The same type of specimens used in the flexural test were used to verify the tensile behavior.

Figure 6 shows the load-displacement relationship of tensile test. The steel bar specimen shows gradual increasing of load and up to 25 ton at peak load. The specimens of FRP pipe without wire shows low load of 17 ton but with wires high load of 28ton. FRP pipe with wires improves the tensile strength and keeps some resisting load at high displacement.

According to the laboratory test results, FRP pipe with wires shows a good engineering properties such as flexural and tensile strengths. Particularly, wires in the pipe can improve the brittle property which is an intrinsic characteristics of FRP pipe.

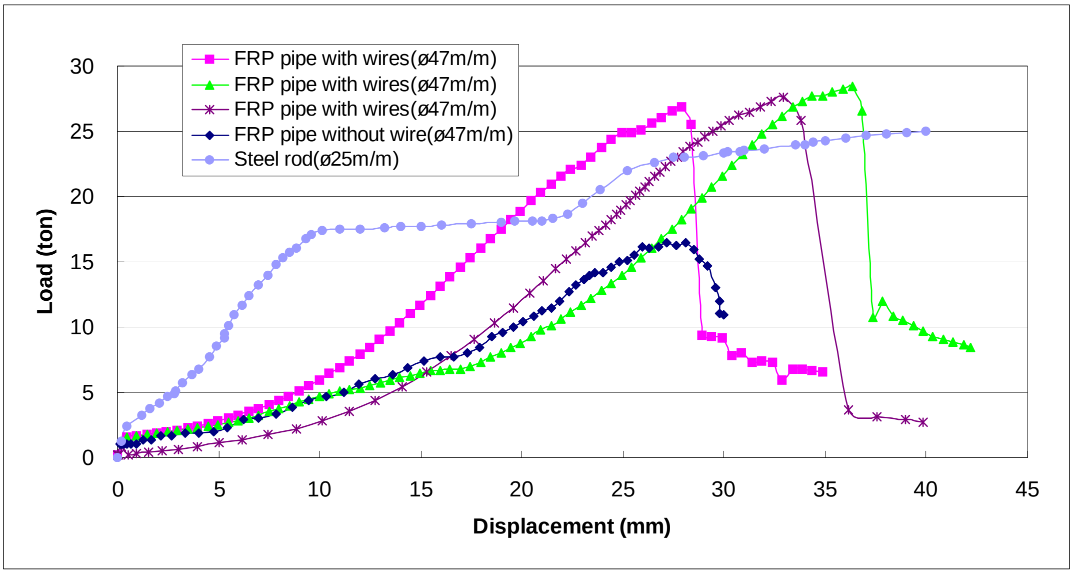

Figure 6. Results of tensile strength test

7. CONSTRUCTION SITE FOR THE FIELD TEST

Field tests were conducted to verify the field applicability of FRP pipe reinforcing method. Rock bolt reinforcing method was applied at the same construction site to compare with FRP reinforcing method. Both methods were applied at three rock slope construction sites which are located at Kyungboo Expressway as shown in Table 3. These three test sites have similar geological conditions. They consists of sedimentary rock which has many joints and bedding planes. Some joints seamed with clayey silt from 2mm to 15mm in thickness. Particularly, a monitoring system was installed in Site B.

Figure 7. View of test site A

Table 3. Locations of test sites

Sites	Length of cut slope (m)	Tested length (m)	Remarks
Test site A	200	60	183 holes
Test site B	420	40	303 holes
Test site C	80	60	123 holes

FIELD TEST

To compare the mechanical properties of the FRP pipe and steel rod reinforcing methods, pull-out test, geophysical test were conducted.

Pull-out Test

The pull-out test were conducted in 10 different locations. They include the proposed three rock slope sites, rock slope of tunnel entrance and two highly weathered cut surfaces and soil embankment sites. As shown in Figure 8, hydraulic jack with load cell, a capacity of 50 ton, was used for the test.

Figure 9 presents results of pull-out test conducted at 10 locations. In the test, FRP pipe causes a slip problem at the fixed end during the test. All specimens including steel rod show a very high tensile strength up to 18 ton. The test was stopped at the proposed load due to failure of base plate and slipping of the crib. There was no failure symptom to be pulled out in the pipe up to the 18 ton. The required pull-out load is 10 ton in Korean design specification.

Geophysical Survey

The electrical resistivity method and seismic refraction method were applied to survey the grouting effect on fissured slope. As shown in the figure 8 and 9, it is not easy to quantitatively calculate the strength change in both surveying methods. It was observed that the seismic velocity and electrical resistivity were changed. In Figure 10, the above and bottom figures present the state of pre-grouting and post-grouting, respectively. There is some change of electrical resistivity in the measured zone as shown in Figure 10(a) and (b). In the figures, the distribution of electrical resistivity in the zone of pre-grouting shows lower resistivity than that of post-grouting. There is not easy to estimate the amount of strength improvement quantitatively in the site applied FRP pipe reinforing method. But it is concluded that the different resistivity distribution quantitatively estimate the effect of cement mortar spreading.

Figure 8. Pull-out test on rock slope

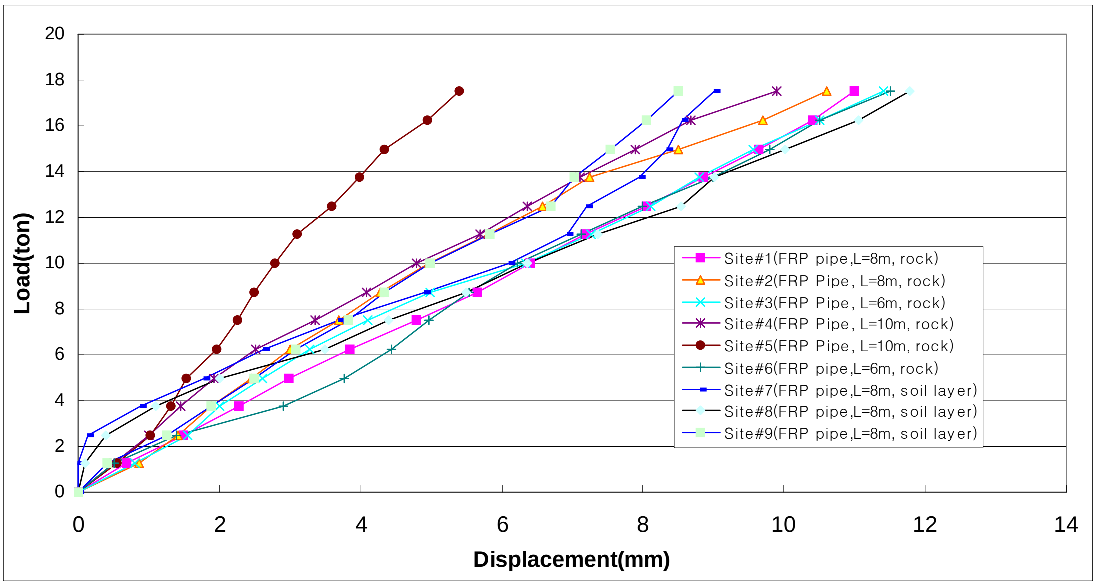

Figure 9. Results of pull-out test at 10 locations

8. CONCLUSIONS

FRP pipe reinforcing method was developed. Laboratory and field tests were applied to verify the function of this method. It was observed that the proposed method showed excellent improvements of the reinforcing method for rock slope as followings:

1) It has a good function of cementing rock joints.
2) It improves the shear strength on the joints.
3) It improves the flexural strength on the joints.
4) It improves the flexural property of FRP pipe.
5) It is easy to handle due to the light weighted material of FRP pipe.
6) It is an economic reinforcing method of rock slope.
7) It is a very useful reinforcing method in the fissured rock slope.

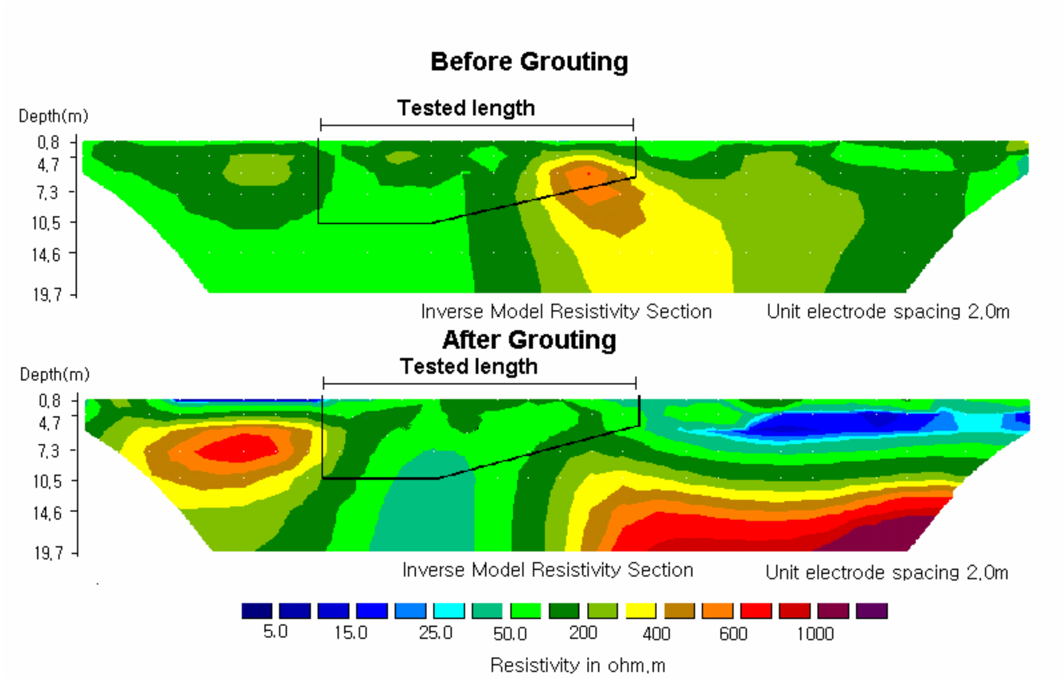

Figure 10. Result of electrical resistivity exploration

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1. Sung-hwan Kim and Nagyoung Kim, 2000, "Development of Slope Reinforcement Method Using FRP-pipe", Korea Highway Corporation, Seoul Korea, Report No. HRC 2000-15.